

Experimental Results of Rover-Based Coring and Caching

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Abstract—Experimental results are presented for experiments performed using a prototype rover-based sample coring and caching system. The system consists of a rotary percussive coring tool on a five degree-of-freedom manipulator arm mounted on a FIDO-class rover and a sample caching subsystem mounted on the rover. Coring and caching experiments were performed in a laboratory setting and in a field test at Mono Lake, California. Rock abrasion experiments using an abrading bit on the coring tool were also performed. The experiments indicate that the sample acquisition and caching architecture is viable for use in a 2018 timeframe Mars caching mission and that rock abrasion using an abrading bit may be feasible in place of a dedicated rock abrasion tool.^{1,2}

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1. INTRODUCTION

A sample caching mission to Mars is under consideration by NASA for a 2018 launch opportunity. This proposed mission would be the first in a series of missions which together would potentially return Mars samples to Earth [1], [2]. It is envisioned that a rover would traverse to various sites and acquire core and soil samples and store them in a sample canister. At the end of the primary mission the rover would traverse to a benign landing area and place the sample canister on the ground. As part of a proposed subsequent mission a fetch rover would traverse from a



Figure 1: Coring and Caching at Mono Lake

lander and pick up and return the sample canister to the lander where it would be placed in a Mars Ascent Vehicle and launched into Mars orbit as the next step toward eventual return to Earth. This subsequent mission might acquire additional samples which would be integrated with a subset of the samples in the return sample canister.

The caching mission rover is anticipated to have a Sample Acquisition and Caching (SAC) subsystem responsible for acquiring core and soil samples, storing them in a sample canister, and placing the canister on the ground. A set of potential requirements for the SAC subsystem was developed in collaboration with the Mars Technology Program, as listed below.

Sample Acquisition:

1. Acquire rock cores with dimension approximately 1 cm wide by 5 cm long.

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²IEEEAC paper #1808, Version 2, Updated January 11, 2011

2. Acquire at least 20 rock cores for return.
3. Acquire samples from five identified rock types: Saddleback Basalt, Volcanic Breccia, Siltstone, Limestone, and Kaolinite.
4. Acquire cores from the top layer of rock.
5. Acquire cores including unmodified surface rind or from rock with an abraded surface.
6. Acquire cores in the tool pitch plane and through 45 degrees from vertical, and maximize the geometry of accessible rock surfaces which could be smooth or rugged with surface normals up to 15 degrees out of the tool pitch plane.
7. Be able to eject a bit that is stuck in a rock.
8. Be robust to anomalous cores, e.g., broken in bit, broken at bit opening.

Sample Handling:

9. Store samples in individual sample tubes.
10. Seal samples in sample tubes to prevent material loss through the seal. Although not a requirement at this time, show if airtight sealing is feasible in the architecture and how it might be done, and show its effects on mass and complexity.
11. Fill the sample canister such that it could be returned to Earth (i.e., close-packed).
12. Be able to place the sample canister on the ground.
13. Sample tubes could be removed from the container for repackaging by another handling system, e.g., on a lander.

System:

14. Operate for at least one Earth year on the Mars surface.
15. Sample from a MER-class rover of mass less than or equal to 300 kg.
16. Minimize the system mass.
17. Be able to reject a sample after acquisition.
18. Sample on slopes up to 25 degrees, including rock and sandy surfaces.
19. Survive catastrophic slip conditions, i.e., if the rover slips down the slope uncontrollably during sample acquisition.
20. Sample acquisition time including tool deployment and extraction from the rock will occur within one Mars daylight period.
21. Measure the sample with 75% volume or mass accuracy.
22. Minimize vibration from the sampling tool to instruments.

23. Minimize sample contamination to satisfy Planetary Protection and Contamination Control requirements.
24. Provide abrading of the surface similar to the functionality provided by the Rock Abrasion Tool of the Mars Exploration Rover mission.

Some related requirements for the sampling and caching rover are listed below.

1. Provide bit change-out.
2. Deploy contact instruments to the surface with a 5 DOF manipulator arm.

The Integrated Mars Sample Acquisition and Handling (IMSAH) system was developed to provide the functionality for the caching mission SAC subsystem [3]. This paper describes results of experiments using an initial prototype of the IMSAH system. The experiments were performed to determine the viability of the proposed IMSAH system architecture in satisfying the anticipated requirements. Coring, caching, rock abrasion, and core orientation experiments were performed in a lab at Jet Propulsion Laboratory. Autonomous coring and caching experiments were also performed in a field test at Mono Lake, California in collaboration with the NASA ASTEP Program AMASE task (PI Andrew Steele), as shown in Figure 1.

Section 2 describes the IMSAH sample acquisition and caching system concept and Section 3 describes the initial IMSAH system prototype that was used for the experiments. Section 4 describes the results of the experiments performed at Mono Lake. Additional coring and caching experiments performed in a lab at Jet Propulsion Laboratory are described in Section 5. Results of rock abrasion experiments using an abrading bit are described in Section 6, a core orientation experiment is described in Section 7, and conclusions are provided in Section 8.

2. IMSAH SAMPLE ACQUISITION AND CACHING SYSTEM ARCHITECTURE

The prototype sample acquisition and caching system used for the experiments has a subset of the capabilities of the Integrated Mars Sample Acquisition and Handling (IMSAH) system which was presented in earlier publications [3], [4], [5]. The three main components of the IMSAH concept are a Tool Deployment Device (TDD), a Sample Acquisition Tool (SAT), and a Sample Handling, Encapsulation, and Containerization (SHEC) subsystem, as depicted in Figures 2 and 3.

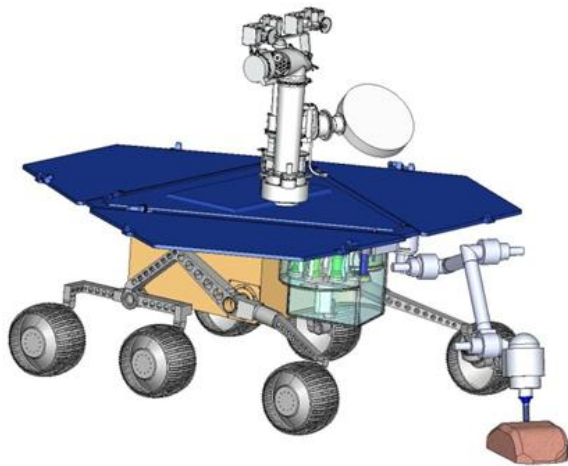


Figure 2: IMSAH coring tool deployment

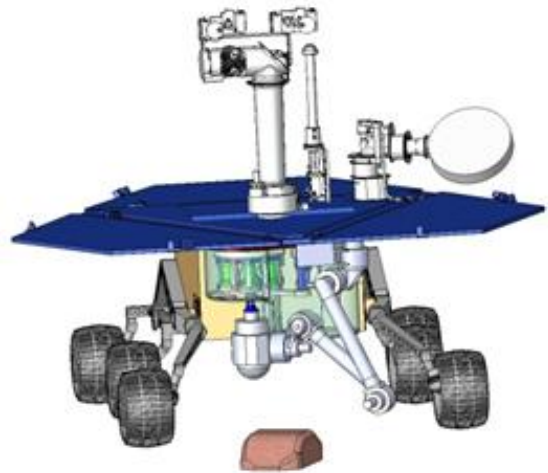


Figure 3: Bit change-out and sample transfer configuration

System Operation

Key elements of the IMSAH system design are listed below.

- Bit change-out would be used to transfer the sample from the coring tool to the sample caching subsystem; bit change-out would be required anyway so it is efficient to add sample transfer to this function.
- The sample would be acquired directly into its sample tube in the coring bit; this would eliminate the risks associated with handling raw samples of unknown geometry.
- Rotary percussion would be used for coring into rocks; rotary percussion requires less weight on bit, does not induce bit walk, and allows for robust hole start relative to rotary drag alternatives.
- Tool deployment, alignment and feed would be accomplished using a 5 degree-of-freedom (DOF) deployment arm; the arm has enough DOFs to provide tool alignment and accommodate modest rover slip.

The operations process for the integrated baseline system is listed below:

1. Deployment arm deploys coring tool to the surface.
2. Coring tool acquires a core directly into its sample tube in the coring bit, breaks off and retains the core; the deployment arm provides tool alignment and feed during coring.

3. Deployment arm transfers the coring tool to the rover-mounted caching subsystem and releases the coring bit in the caching subsystem.
4. Caching subsystem removes the sample-filled tube from the coring bit, measures the sample, seals the tube, and stores the tube in the sample canister.
5. Caching subsystem puts a new sample tube in a coring bit.
6. Deployment arm transfers coring tool to the caching subsystem and coring tool attaches bit. Process then repeats

Tool Deployment Device

The tool deployment device (TDD) manipulates the coring tool including positioning and aligning the coring tool at the target, providing preload between the SAT and environment, and providing tool feed during the sampling operation. It also positions the SAT for bit changeout at the SHEC, as described below. A five degree-of-freedom (DOF) manipulator arm is used in the proposed IMSAH architecture for sampling tool deployment. An alternative architecture that was considered utilized a lower DOF deployment device, e.g. a pitch-translate, “body mount” mechanism which could deploy the coring tool to a sampling location but with reduced positioning and alignment capabilities. In the IMSAH architecture, the arm actuator brakes can be set when the coring tool is active so that the arm actuators do not draw power when coring.

Sample Acquisition Tool

The Sample Acquisition Tool (SAT) utilizes rotary percussion for coring and also provides core breakoff, core retention, and active bit capture and release for bit changeout. The tool has a passive linear spring which the

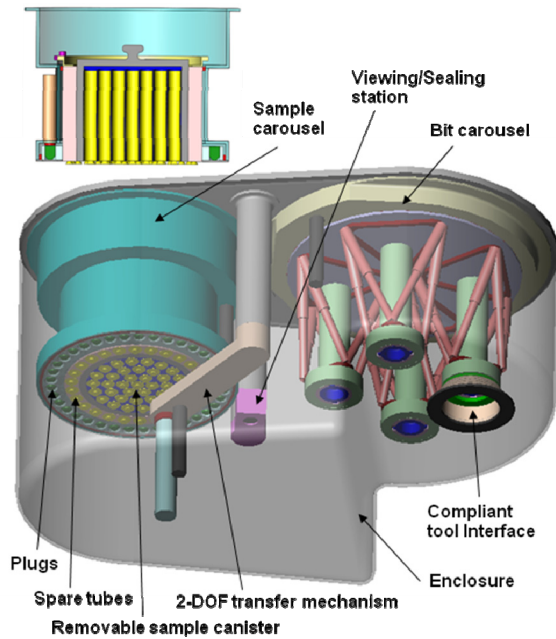


Figure 4: Bit change-out and sample transfer configuration

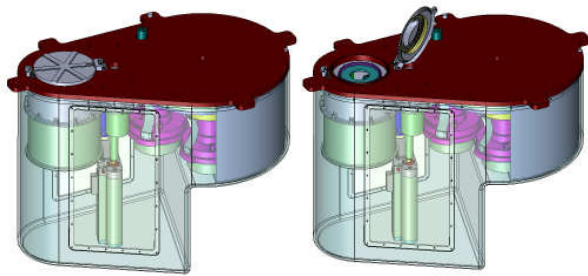


Figure 5: Hatch opening for sample canister removal

arm preloads. The linear spring then provides the preload and linear feed during one coring segment, typically about 1 cm, after which the arm realigns the coring tool and resets the preload. A new sample tube is placed in the coring bit for each sample. A coring tool with these functions has been designed and is being fabricated for use in future experiments.

Sample Handling, Encapsulation, and Containerization (SHEC) Subsystem

The Sample Handling, Encapsulation, and Containerization (SHEC) subsystem has four primary components, the bit carousel, the sample carousel, the transfer arm, and the sealing station, as shown in Figures 4 and 5, with prototype shown in Figure 6. The bit carousel stores and presents bits for bit changeout with the coring tool. There is one open bit port in the SHEC enclosure where a bit can be transferred to

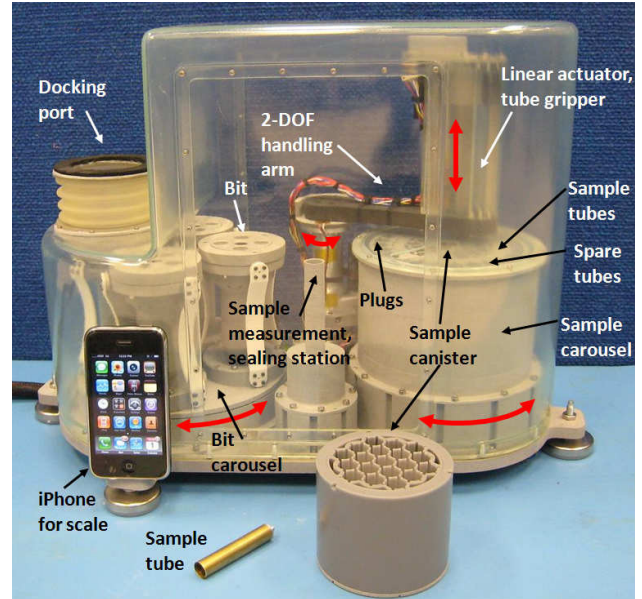


Figure 6: SHEC subsystem prototype

or from the SAT. The transfer arm rotates between the bit carousel, sample carousel, and sealing station. It has a tube gripper that grips a knob on a sample tube and a linear actuator that pulls a tube out of or inserts a tube in a chamber in the sample canister or a coring bit. The sample carousel has the sample canister in the center and tube plugs and spare tubes around the canister. The canister can be removed from the sample carousel out of a hatch at the top of the SHEC, as shown in Figure 5.

3. PROTOTYPE SAMPLE ACQUISITION AND CACHING SYSTEM

An initial prototype sample acquisition and caching system with a subset of the IMSAH functionality was integrated onto a FIDO-class rover for the purpose of evaluating the proposed architecture, as shown in Figure 7. The prototype system has a five DOF deployment arm and a rotary percussive coring tool mounted to the arm via a linear spring as per the system design. A six axis force-torque sensor mounted to the manipulator wrist provides force sensing for preload and alignment by the manipulator arm.

The prototype coring tool weighs 2.5 kg and provides rotary percussion for coring with rotation and percussion coupled and driven by a common actuator. The prototype coring tool does not provide core breakoff, core retention, or automated bit changeout which would be provided by the coring tool of the complete system design.

The prototype caching subsystem, shown in Figure 6, provides the primary capabilities of the proposed system. A single bit docking port provides access to the internal



Figure 7: Coring and caching system at Mono Lake

caching subsystem. A bit is inserted by hand into the bit port where the bit is retained in a bit chamber. A sample tube is autonomously removed from a bit, transferred to the sample carousel where a plug is autonomously inserted, transferred to the plugging station where the plug is pushed into the tube until it contacts the sample, and the filled sample tube is inserted into a chamber in the sample canister. An empty sample tube is extracted from the sample canister and autonomously inserted into a coring bit in the bit carousel and the bit is rotated to the bit port where it is manually removed and manually attached to the coring tool.

The coring operation has five steps, hole-start, core generation, core break-off, bit extraction, and bit removal. The hole-start step starts by aligning the bit normal to the surface at the sampling target.

The hole-start algorithm is listed below.

1. Preload bit.
2. Rotary percussion coring for 10seconds.
3. Lift bit and place back down on target using only linear motion.
4. Repeat steps 1 to 3 until the bit has entered the rock 5 mm which is enough to be constrained in horizontal motion.

The hole-start algorithm constrains the motion of the bit to linear motion along the bit axis and replaces the bit on the surface at each iteration to prevent bit walk. In bit walk the bit moves horizontally along the rock surface. Horizontal force accommodation is not needed before the bit is constrained in the rock. Replacing the bit on the target at each iteration is useful when the bit is misaligned with the rock surface – it resets the hole position after small bit motion down the rock surface during each step.



Figure 8: Coring tufa rock 1

The core generation step adds realignment of the bit after each coring iteration. The core generation algorithm is listed below.

1. Preload bit.
2. Align bit.
3. Rotary percussion coring until bit preload reduces to 75% of preload force, then stop coring.
4. Repeat steps 1 to 3 until core depth has been reached.

Realignment of the bit utilizes the six axis force-torque sensor data and moves the bit to eliminate lateral forces.

4. MONO LAKE FIELD TEST RESULTS

The prototype sample acquisition and caching system was utilized in a field test at Mono Lake, California, as part of the NASA Astrobiology Science and Technology for Exploring Planets (ASTEP) program Arctic Mars Analogue Svalbard Expedition (AMASE) task. The AMASE task performed science experiments which are out of the scope of this paper, but also utilized the prototype IMSAH system for autonomous coring and caching which generated results which are presented here.

The Coring and Caching Experiments

The coring and caching experiments at Mono Lake were performed at two locations. Since it was raining during the first days of the field test, the rover was placed in a room at Lee Vining High School and the science team acquired a large tufa rock and brought it into the room for acquisition of three cores. On the last day of sampling, the weather improved and the rover was taken to the western shoreline



Figure 9: Coring tufa rock 2



Figure 11: Cored hole in tufa rock 2



Figure 10: Coring tufa rock 3



Figure 12: Core from tufa rock 2

of Mono Lake where further coring and caching experiments were performed. Images of the coring and caching experiments are shown in Figure 1 and Figures 7 - 15.

Results: Tool Deployment Architecture

The experiments demonstrated the benefits of using a 5 DOF arm for tool deployment. There were two primary alternatives for tool deployment, a 2 DOF pitch-translate “body-mount” architecture and the 5 DOF “arm-mount” architecture of the IMSAH architecture. The 5 DOF arm-mount architecture was used in these experiments. Figures 8-10 show the three rocks that the scientists selected to core.

In each case the selected target to core would not have been accessible by a body-mount tool deployment architecture. The surfaces were so rugged that alignment for coring required 5 DOFs in the deployment device. It is felt that if a body-mount deployment device was used, the roughness of the surfaces would have required realignment of the tool in

DOFs not available with a body-mount deployment device. While rocks with sampling targets that potentially could be cored with a body-mount architecture may have been found, they would have significantly limited the science target options during the field test, and in similar circumstances, a mission.

Results: Tool Alignment and Feed with Arm

The experiments demonstrated the IMSAH architecture approach for tool alignment and feed. Two primary architectures for tool alignment and feed had been considered, first an architecture utilizing mechanical tines for alignment and a drill feed actuator in the coring tool, and second the IMSAH architecture where a 5 DOF arm provides tool positioning, alignment, preload, and feed and the tool has a linear spring that is reset by the arm. The first architecture is being utilized successfully in the Mars Science Laboratory mission for drilling similar size holes

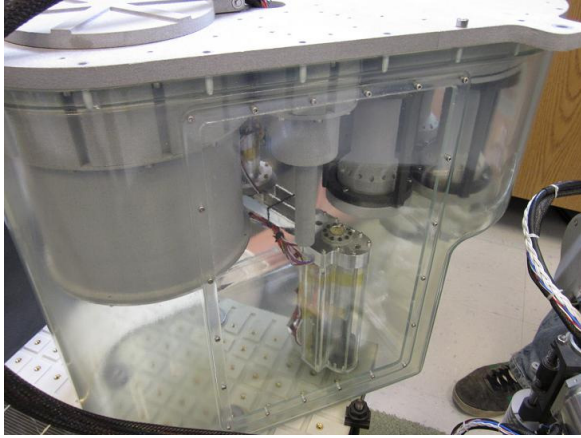


Figure 13: SHEC with sample in tube

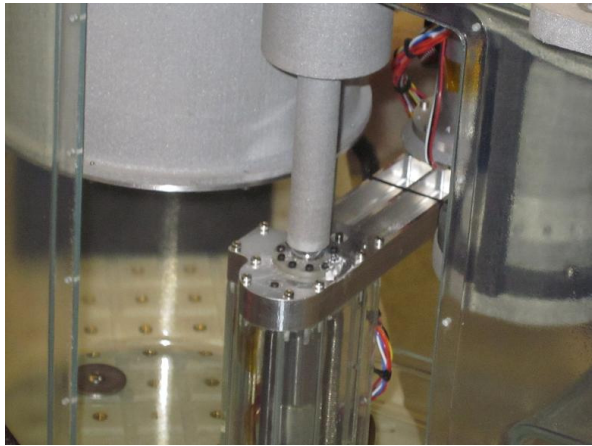


Figure 14: Sample tube at sealing station

from its rover [6]. But the MSL rover is about 900kg with sufficient mass allocation to allow for a drill of about 17kg and arm that can apply about 300N of force to press the tines against a rock to provide tool stability during coring. The proposed 2018 caching mission rover may weigh on the order of 350kg and therefore would have a much lower mass allocation for the sample acquisition and handling system. Using the IMSAH architecture in the field test, the arm exerted only 10N of bit preload during the hole-start operation and 20N of preload during the coring operation. The arm was able to provide the positioning, alignment, bit preload, and drill feed (via the tool linear spring) to successfully core the rocks.

The hole-start algorithm was updated after the Mono Lake field test to improve the preservation of the surface rind at the top of rock cores. In the Mono Lake field test the core generation algorithm was used for hole-start. Since this included lateral motion to accommodate side loads, it was observed that the bit moved laterally up to about 1cm during the hole-start process. This resulted in the surface rind often being abraded. After the field test the hole-start algorithm

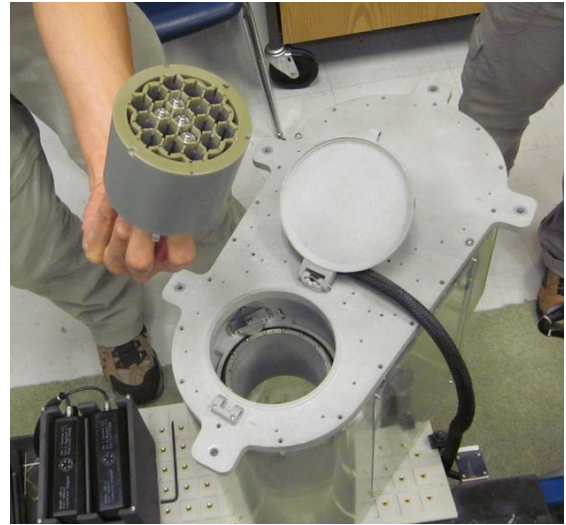


Figure 15: Sample canister removal

described in Section 3 was implemented to reduce bit walk and was used in the coring experiments done in the lab, as described in Section 5.

Results: Sample Acquisition Directly into Tube

Cores were acquired directly into sample tubes in the coring bit in the field test. This approach to sample encapsulation worked well. The foul weather may have been beneficial in understanding the benefits of acquiring samples directly into their sample tubes. Before the field test, dry rock cores were regularly successfully acquired directly into their sample tubes in laboratory experiments and had clearance between core and tube. But some of the samples acquired during the field test were damp and molded like clay resulting in being packed tightly in the sample tubes. As discussed below in the sealing results, it was difficult to push the samples further into the tubes. It is felt that if an alternative architecture was used for sample transfer where samples were pushed out the front of the coring bit into sample tubes, then the samples may have been jammed in the bit and unable to be pushed out. This would result in loss of a coring bit, whereas with the IMSAH architecture a tube could be rejected with much less impact.

Results: Caching Architecture

The sample caching subsystem successfully performed all of its operations. It removed a sample tube from a coring bit, transferred it to the sample carousel and inserted a plug and then transferred it to the sealing station and pushed the plug into the tube into contact with the sample and then inserted the tube in the sample canister. Figure 13 shows the caching subsystem transferring the sample from the bit to the sample carousel for plug insertion. Figure 14 shows the plug in the tube at the sealing station. The system extracted an unused sample tube from the sample canister

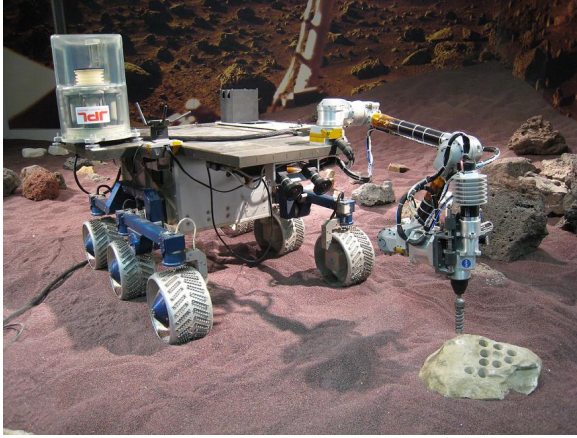


Figure 16: Lab testing environment



Figure 18: Hole partially started



Figure 17: Misaligned bit at start of hole-start



Figure 19: Hole completed on misaligned surface

and inserted it into the coring bit in the bit carousel. After caching samples, the sample canister was manually removed from the top of the caching subsystem, as shown in Figure 15. Several areas of improvement for the caching subsystem were identified. First, the preliminary autonomy and control system utilized open loop moves and minimal status checking. The open loop motions generally worked well but it is expected that there would have been errors in positioning if the weather had been warmer since then the mechanism would have experienced some warping and the calibrated open loop moves would likely have often missed the close tolerance insertions. Second, the plugging operation did not always work well, as described below.

Results: Sample Sealing with Plug

Utilizing a plug to seal the sample tubes did not always work in the field test due to the sample being jammed all the way at the top of the sample tube and the plugging operation unable to push the sample further into the tube to make room for the plug. This problem had not been observed in a laboratory setting where the rocks were dry.

The damp samples of the field test got jammed in the tube. To accommodate this problem the new version of the caching system that is being fabricated will have a stronger linear actuator to push the sample into the tube. Also, it is felt that the samples in a mission will not be sticky like the damp samples of the field test. An alternative solution would be to use tube caps rather than plugs. The architecture would support the change to caps in place of plugs but that is a less desirable solution since caps result in increased tube diameter and therefore canister diameter and the sample measurement feature of plugs would be lost. The issues associated with pushing the sample into the tube will continue to be investigated before a final design decision for sealing is selected.

5. CORING AND CACHING LAB EXPERIMENTS

Additional experiments to core and autonomously cache rock samples were performed in the Planetary Robotics



Figure 20: Kaolinite (top) and sandstone (bottom) core samples with sample tube

laboratory at Jet Propulsion Laboratory, as shown in Figure 16.

Testing of the hole-start algorithm is shown in Figures 17-19. Figure 17 shows the coring bit misaligned with the surface of a sandstone rock by 19 degrees. The hole-start algorithm described in Section 3 was used to start the hole, with the results shown in Figures 18 and 19 (the cuttings were vacuumed away for the pictures to better show the status of hole-start). Figure 18 shows that the bit was able to cut away at the higher surface without exhibiting bit walk, and Figure 19 shows that hole-start was completed without bit walk and while maintaining the surface rind.

Coring experiments were performed to determine the viability of acquiring cores directly into sample tubes. Figure 20 shows cores acquired in kaolinite and sandstone. The kaolinite cores have one to three segments. The sandstone cores are fractured into numerous disks which

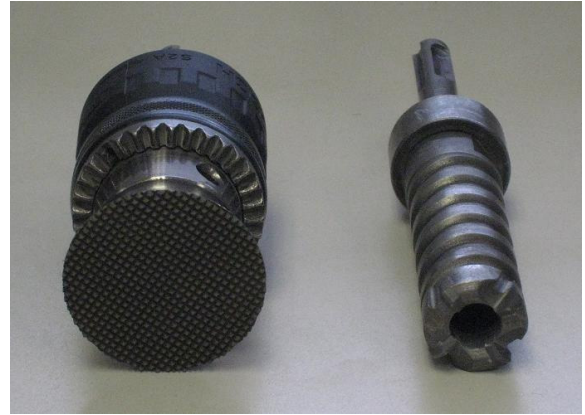


Figure 21: Abrading bit next to coring bit



Figure 22: Abrading limestone

would be satisfactory but fewer segments is desirable and is anticipated from the new coring tool currently being fabricated.

Caching experiments were performed to determine the effectiveness of the SHEC caching concept. A coring bit with a core in a sample tube was manually inserted into the bit port of the SHEC and the sample was then autonomously cached including removal of the tube from the bit, transfer to the sample canister where a plug was inserted into the tube, transfer to the sealing station where the plug was pushed into contact with the sample, and insertion of the sample tube into the sample canister, followed by removal of an empty sample tube from the sample canister and its insertion into a coring bit. The kaolinite and sandstone cores were autonomously cached.

6. ABRADING BIT EXPERIMENTAL RESULTS

Preliminary laboratory experiments were performed to evaluate the feasibility of utilizing an abrading bit in place of a rock abrasion tool to abrade rock surfaces. The Mars Exploration Rover mission rovers have a Rock Abrasion

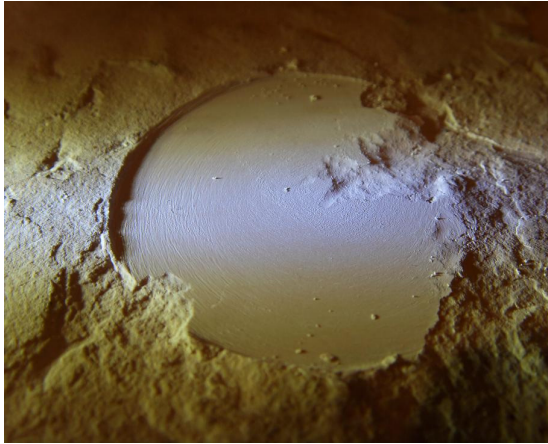


Figure 23: Abraded limestone (after cuttings removal)



Figure 24: Abraded Saddleback basalt

Tool (RAT) on the turret of the arm which is used to abrade the surfaces of rocks [7]. The RAT worked well, but there would be significant motivation to seek lower mass solutions to the abrasion requirement given the likely mass of drilling and science instruments that would be accommodated on the arm. It may be possible to provide the required functionality for rock surface abrasion with minimum mass and volume on the turret by attaching an abrading bit to the coring tool using the same interface as used for bit changeout.

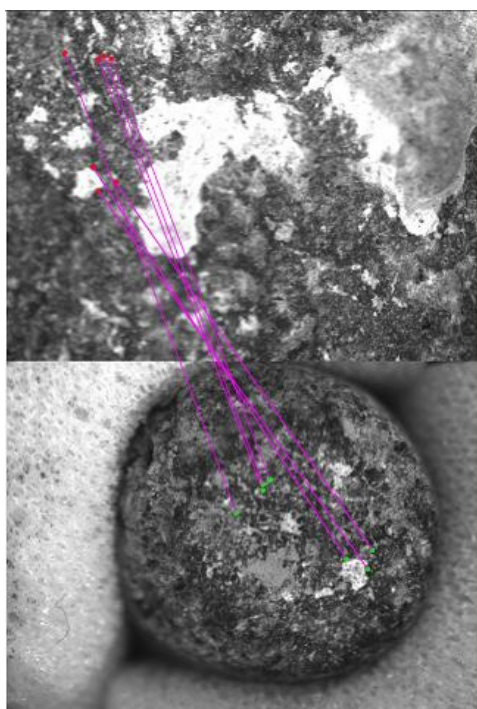


Figure 25: Abraded Archean altered basalt before cuttings removal

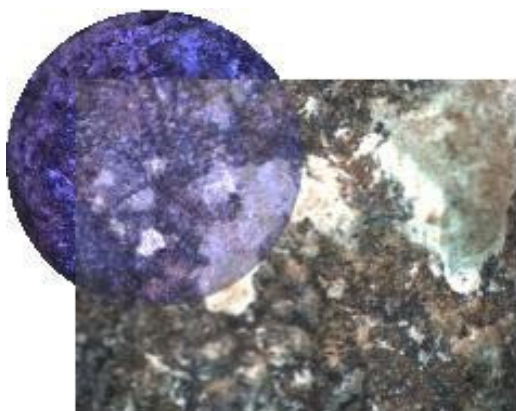
The functionality requirements of an abrasion tool would be determined by the types of science measurements that would be carried out by the potential 2018 rover, and the instruments needed to carry out those measurements. These measurements have been discussed by the Mid Range Rover Science Analysis Group (MRR-SAG) [8]. Emphasis would be on arm-mounted, high spatial resolution (e.g. sub-millimeter spot size) measurements of elements, minerals and organic materials in rock outcrops and boulders. Possible micro-analytical instruments that could perform these measurements are: green laser Raman spectrometer for minerals, UV laser Raman spectrometer for organics, and micro-X-ray fluorescence for elemental chemistry. The aim of using such micro-analytical instruments would be to correlate small scale variations in composition with microstructures and textures seen with a close-up imager. The surface would need to be smooth enough to allow the science measurements to be performed adequately. If a green laser Raman spectrometer were included in the payload, this could be a driving factor for surface smoothness as green laser Raman measurements require a smooth surface in order to minimize problems with fluorescence. If a smooth enough surface is not attainable, opto-mechanical solutions are possible, but these increase instrument complexity, mass, and developmental risk.

Abrading bit experiments

We conducted a preliminary evaluation of the ability of an abrading bit to expose fresh rock surfaces for micro-analysis by techniques that might be included on the potential 2018 rover. Figure 21 shows the abrading bit. The bit was attached to the coring tool on the arm and 10N of preload was applied to the arm while the tool applied rotary



(a)



(b)

Figure 26: (a) Microscopic image (MI) of parent rock and top of core with matched features, (b) overlay of MI of core top and parent rock

percussive action (Figure 22). Figures 22-25 show results of preliminary tests using the abrading bit.

The abrading bit successfully abraded the surfaces of soft (limestone, claystone) and hard (Saddleback basalt, Archean altered basalt) rock types. The hardest rock type—Archean chert—could not be abraded successfully with the bit. Figures 23-25 illustrate the abraded rock surfaces. Cuttings accumulated around the circumference and in low parts of the abraded circle, and were removed manually. Figure 23 shows abraded limestone after cuttings removal and Figures 24, 25 show abraded Saddleback basalt and Archean altered basalt before cuttings removal. The experiments show that a

means for cuttings removal is critical as cuttings are otherwise likely to obscure the rock surface (Figures 24, 25).

The surfaces produced by the abrading bit appear relatively smooth to the naked eye, with only fine curved scratches similar to those produced on a rock surface that has been cut with a diamond saw blade. Millimeter-scale micro-textural features are distinguishable in the Archean altered basalt (Figure 25). The surface is smooth enough for micro-X-ray fluorescence analysis using a Horiba XGT -5000 benchtop instrument with a 100 μ m spot size. However, the surface roughness is likely to pose problems for green laser Raman analysis, depending on the target material, unless fluorescence-reducing approaches (e.g. extremely small spot sizes, time-gating, auto-focusing) are employed.

Generation of a smoother surface will be desirable not only for the potential analytical techniques that may be used, but also for better imaging resolution of visible features. Concepts for further development of an abrading bit are underway to result in a smoother surface with cuttings removal. The ability to abrade harder rock types than Saddleback basalt is also desirable as many of the rocks that are best for biosignature preservation—such as chert—have low permeability and high hardness.

It is unlikely that an abrading bit could be developed that would work better than a dedicated Rock Abrasion Tool. However, an abrading bit might be developed that provides satisfactory abrasion capabilities with the added benefit of reduced system mass.

7. CORE ORIENTATION EXPERIMENTS

An experiment was performed to assess the viability of using microscopic imagery to document the orientation of a core sample in its parent rock. A microscopic image (MI) of the parent rock was acquired before acquisition of a core (top image in Figure 26 (a)) and then another MI was taken of the top of the core acquired at that location (second image in Figure 26 (a)). The microscopic images of the rock surface before and after core acquisition were aligned using a Scale Invariance Feature Transform (SIFT) operator applied to both images for feature extraction and matching [9]. The use of SIFT features allows images of the same object to be aligned across varying scale and rotations. Lines indicate matched features in the two images. Figure 26 (b) shows an overlay of the matched images.

The orientation of the original rock would be determined by its orientation relative to the rover. As shown in Section 5, it is expected that some cores will be broken into multiple segments, and these segments might rotate relative to each other. Therefore use of microscopic imagery to determine core orientation will likely be limited to determining the

orientation of only the top segment of a core. There may be cases where the rock surface is very homogeneous which will make matching the rock core surface image with the original rock surface difficult so further study of this approach will be needed.

8. CONCLUSIONS

Experiments were performed that demonstrate the viability of the IMSAH sample acquisition and caching architecture for a 2018 timeframe Mars caching mission. Other experiments demonstrated the potential for use of an abrading bit in place of a dedicated rock abrasion tool and microscopic imagery to document the orientation of core samples. The abrading bit experiments showed that an abrading bit can abrade soft and hard rocks but further work is needed to identify a way to provide cuttings removal and generate smoother surfaces. Microscopic imagery to determine core orientation is limited by cores being broken into segments that can rotate relative to each other. These initial experiments have provided information on how to focus further research in the development of the next generation of the sample acquisition and caching system and an abrading bit.

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BIOGRAPHY



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